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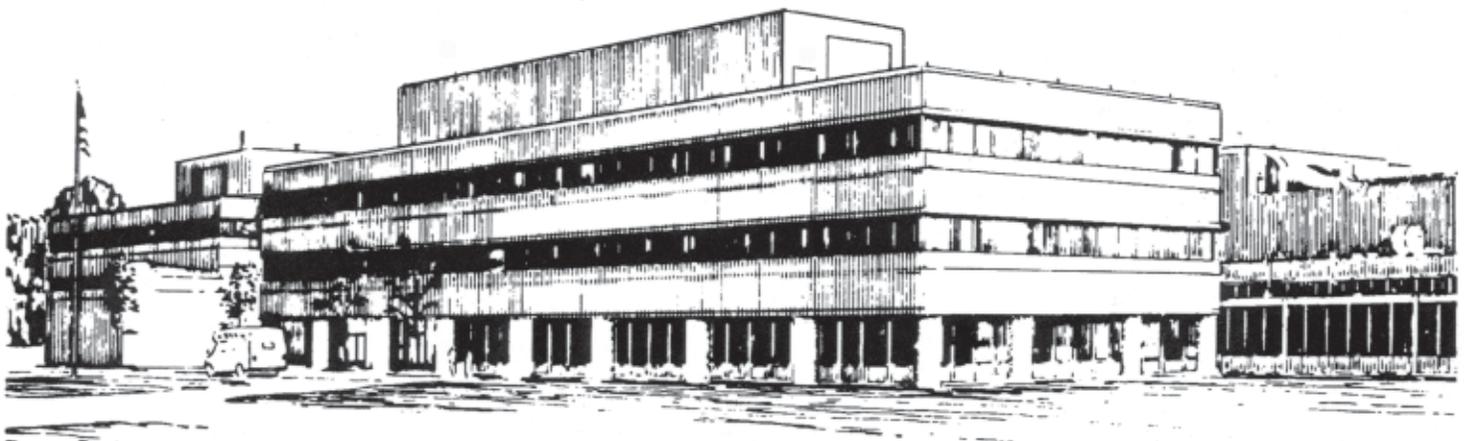
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by

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Lithium Pellet Injector Development for NSTX

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Abstract - A pellet injector suitable for the injection of lithium and other low-Z pellets of varying mass into plasmas at precise velocities from 5 to 500 m/s is being developed for use on NSTX. The ability to inject low-Z impurities will significantly expand NSTX experimental capability for a broad range of diagnostic and operational applications. The architecture employs a pellet-carrying cartridge propelled through a guide tube by deuterium gas. Abrupt deceleration of the cartridge at the end of the guide tube results in the pellet continuing along its intended path, thereby giving controlled reproducible velocities for a variety of pellets materials and a reduced gas load to the torus. The planned injector assembly has four hundred guide tubes contained in a rotating magazine with eight tubes provided for injection into plasmas. A PC-based control system is being developed as well and will be described elsewhere in these Proceedings. The development path and mechanical performance of the injector will be described.

I. INTRODUCTION

The National Spherical Torus Experiment (NSTX), located at the Princeton Plasma Physics Laboratory, is evaluating the physics principles of a spherical torus (ST) geometry and has been extensively described elsewhere [1]. The NSTX research plan calls for the capability to inject small solid or micro pellet ensembles of lithium, and other low-Z impurities for operational and diagnostic applications. These include 1) wall conditioning, 2) measuring edge impurity transport, 3) inducing edge transport barriers, 4) measuring $q(r)$ profiles, 5) probing edge flows and rotation, 6) enhancing charge exchange signals, 7) controlling disruption decay rate, and 8) lithium limiter simulation. Garzotti, *et al.*, have described a pneumatic injector using a shuttling cartridge to convey a pellet to its launch point[2]. This effort served as a solid starting point for the NSTX injector development path.

II. PROTOTYPE EFFORTS

Figure 1 shows the output end of the single guide tube injection assembly used to qualify the concept of

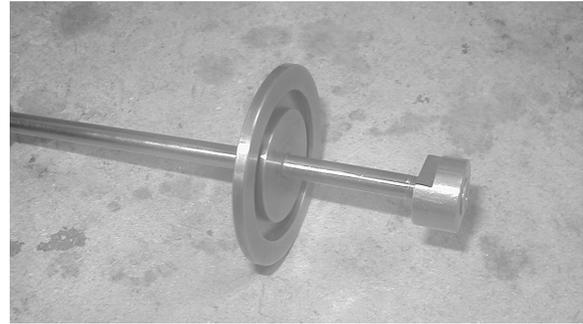
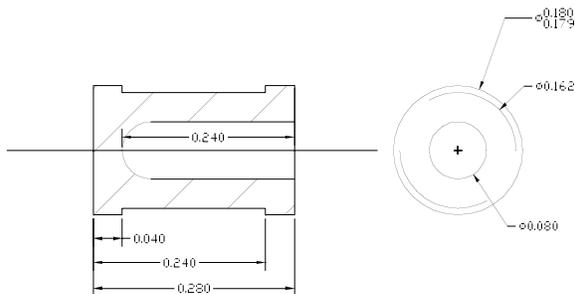
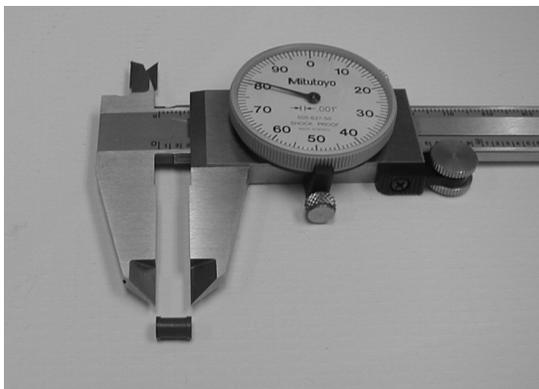


Figure.1. Prototype Single Guide Tube injector.

a pneumatically driven, pellet-bearing cartridge being abruptly decelerated at the end of its translation. The guide tube is of AISI 304 stainless steel seamless tubing having an outside diameter of 0.250 inches and a wall thickness of about 0.035. A 0.182 inch reamer was applied to each twelve-inch long guide tube to assure a consistent bore. An ISO(KF) 40 vacuum interface flange was selected to facilitate the frequent demounting associated with the reloading of the injector after each shot. A final and important feature of the prototype injector is the cartridge stop subassembly (the “stop”) at the output end. The stop has an internal female thread that screws onto the male threaded OD of the guide tube. The opposite end of the stop has a removable, screwed plug with two significant features. First, the plug has an exit bore of 0.125 inches and, secondly, the plug holds a flat washer-shaped Viton seal with a similar bore inside the stop. When the stop is threaded onto the guide tube, the faced-off end of the tube contacts against the Viton seal. This sealing contact becomes a significant gas limiting feature.

Figures 2a & 2b show the details of a typical Vespel grade SP-1 polyimide cartridge. The 0.180 inch outside diameter of the cartridge complements the 0.182 bore of the guide tube to yield a low clearance sliding fit. Polyimide was selected both because sliding friction in the guide tube was expected to be minimal and because “sticky” substances such as lithium are expected to free themselves easily from the cartridge during launch/cartridge deceleration.



Figures 2a & 2b. VespeL Polyimide Cartridge.

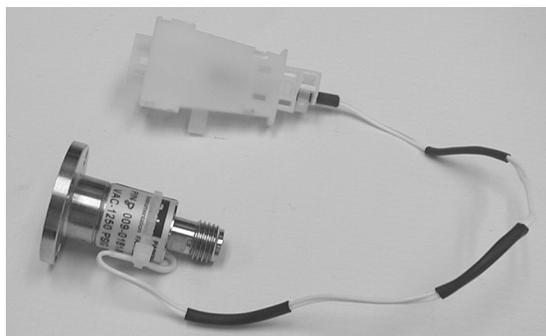


Figure 3. Parker Series 9 Valve.

The Viton seal contained in the stop and described above serves as the contacting element that absorbs the energy of cartridge deceleration and tends to seal the volume of the guide tube bore from the downstream target vacuum system. This “seal” has such a low conductance to the target chamber that the eventual pressure rise in the target chamber from delayed admission of propellant gas occurs mostly after an NSTX plasma has terminated.

Figure 3 shows a Parker Hannifin Series 9 solenoid-operated valve used during the prototype investigation. The valve has the combined attributes of small size (1.06 inch flange OD) and quick response. Valve opening time can be as little as 180

microseconds giving researchers and operations personnel fine control over propellant drive.

Figure 4 shows traces archived from a particular pellet flight. The first trace shows the output from the valve controller energizing the valve for 8 ms. The second trace shows the response of the piezoelectric element mounted on the valve suggesting the cartridge encountered the stop at 9.5 ms. The third trace in Figure 4 shows the

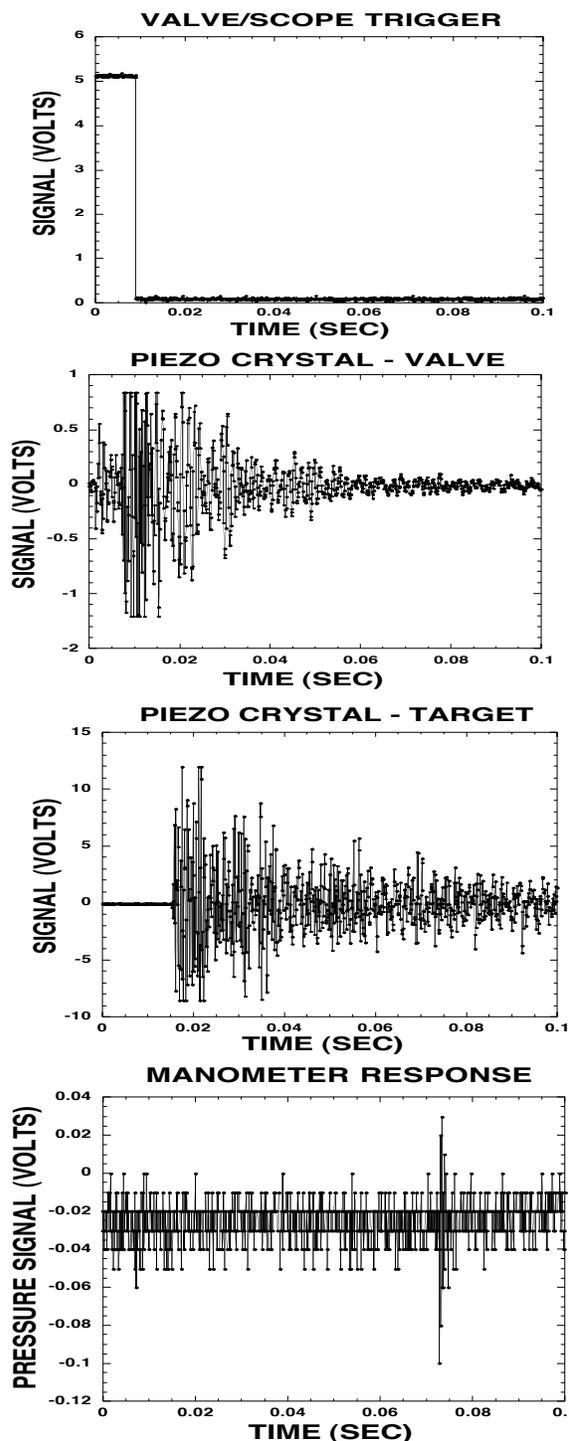


Figure 4. Typical Prototype Pellet Event.

0.03 inch diameter by approximately 0.08 inch-long aluminum pellet arriving at the piezoelectrically-monitored target about 16 ms into the trial. Given a distance from the stop to the target of about 0.66 meters, an average velocity of 94 m/s is calculated. The fourth trace in Figure 4 shows the first response of the capacitance manometer measuring the target chamber pressure occurring at 72 ms. Total best-case gas loads of 5 Torr-liters have been observed. Launching pellets into plasmas later than $t=0$ seconds will lessen the contribution of deuterium gas through this avenue.

III. COMPLETE INJECTOR ASSEMBLY

Figure 5 shows a depiction of the now-fabricated pellet injector with 400 guide tubes mounted in a rotating magazine having 50 zones of 8 tubes; each on a radial line. The magazine is suspended in a main vacuum chamber and rotated by a drive including a stepper motor, encoder, and a bellows-sealed rotary feedthrough.

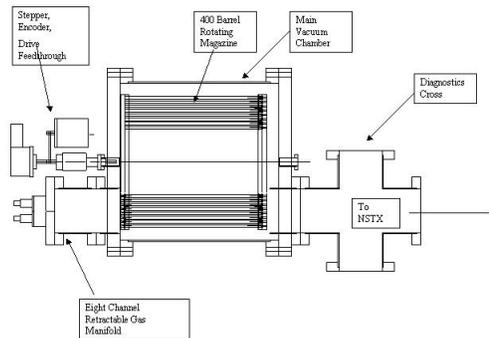


Figure 5. Complete Pellet Injector.

An eight-channel gas manifold aligns and engages with the selected zone of eight guide tubes motored to the firing position. Finally, a vacuum cross is provided in the flight path to the NSTX vacuum vessel for the inclusion of laser and piezoelectric diagnostics to allow velocity measurements and propellant gas control, if needed.

A well-considered control scheme has been devised by Princeton's computer and electrical engineering staff and described by Sichta, *et al.* [3]. A significant aspect of the control approach is the ability to quickly switch (50 ms/switch) the valve driver between the eight Parker Series 9 gas admission valves mounted on the manifold. This capability will allow multiple pellet flights during a single plasma.

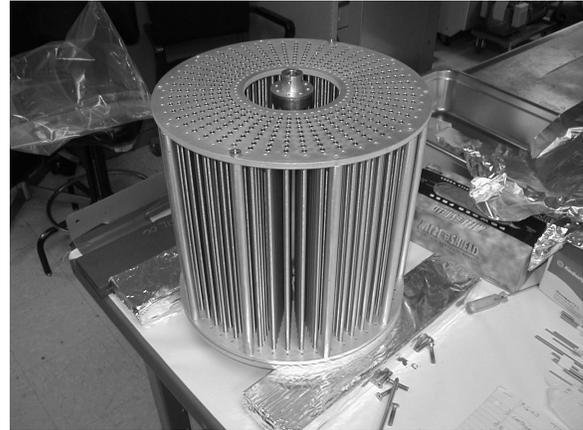


Figure 6. Magazine Subassembly.

Figure 6 shows the partially-assembled 400-tube magazine with the tube-ends exposed. Each end of the magazine has a 0.063 inch Viton sheet with 400 appropriately sized and located holes for isolating the guide tube bores (and propellant gas) from the vacuum system. This theme will be continued below.

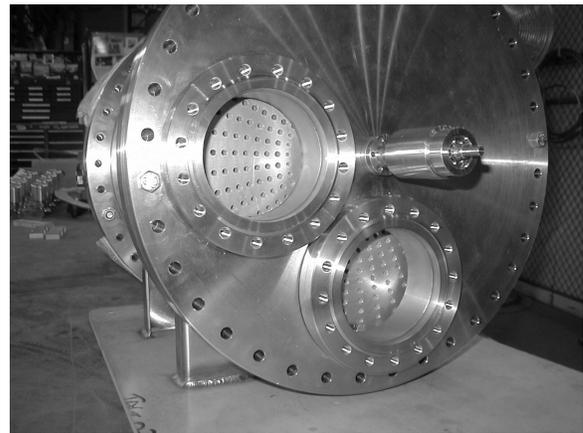


Figure 7. Magazine in Main Chamber.

Figure 7 shows the magazine mounted in the chamber. The 8-tube zone (one of 50 zones, total) centered in the low port receives the gas manifold assembly, shown in Figure 8. The gas manifold has eight Parker Series 9 gas admission valves mounted to it in a 2 high x 4 wide rectangular array to allow for a magnetic shield enclosure (not shown). This 2 x 4 array is converted to a 1 wide x 8 high pattern having the spacing of the 8-tube magazine zone by means of a cross-milled plate that is vacuum brazed between a 6 inch Conflat flange and the 2 x 4 pattern adapter plate, both shown in Figures 9a & 9b. Note also in Figure 8 that an eight-channel Viton nose seal is fitted across the nose of the gas manifold assembly.

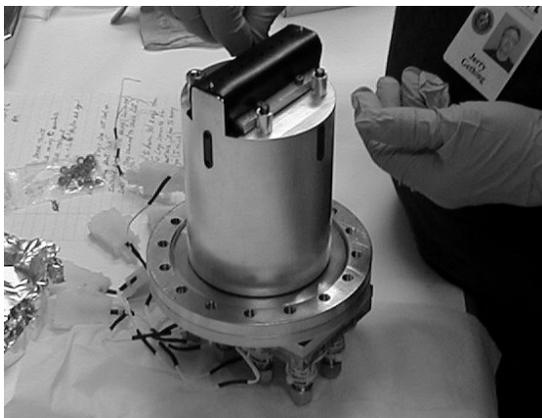
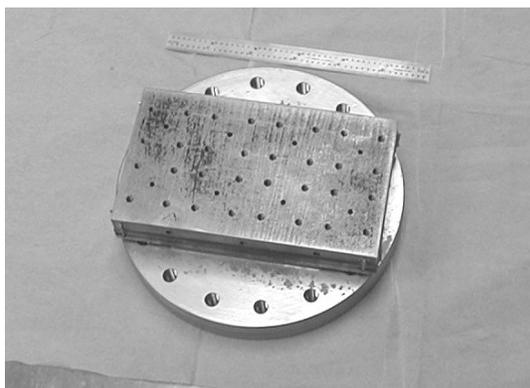
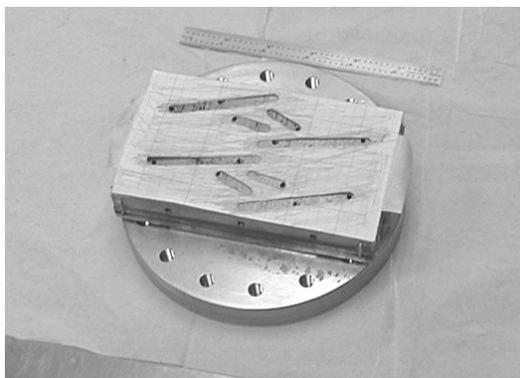


Figure 8. Gas Manifold Assembly.

This nose seal, along with the previously-mentioned Viton sheets included at the tube ends in the magazine assembly, establish propellant gas containment in effectively the same manner demonstrated with the prototype injector.



Figures 9a & 9b. Cross-Milled Manifold Plate and Complete Brazed Assembly.

Figure 10 shows a partial assembly of the gas manifold inserted in the firing port of the main chamber. A vacuum bellows (not shown) seals the vacuum system and allows retraction of the gas

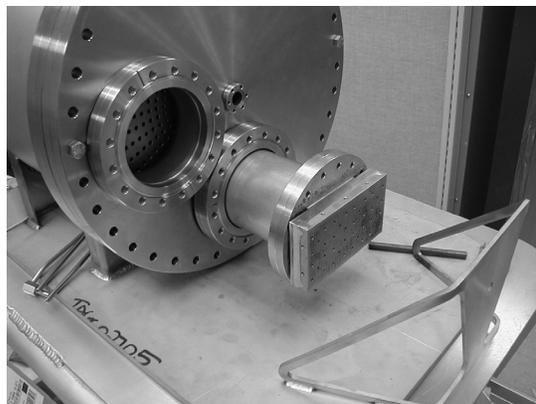


Figure 10. Partial Gas Manifold Place in Main Chamber (vacuum bellows omitted).

manifold assembly slightly to permit the rotation of the magazine to the next desired 8-tube zone.

IV. SUMMARY AND CONCLUSIONS

The lithium and low-Z injector proposed for service on NSTX benefits from lessons learned in both cryo and ambient temperature pneumatic injectors built for the fusion community. The suitability of a cartridge-employing injector has been demonstrated in a prototype program and hardware and controls for a 400 tube injector are well under way. Injection into NSTX plasmas, with potential for as many as eight pellets per shot, is planned for the run period in FY '04.

ACKNOWLEDGMENT

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